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(54) Thermosettable composition

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Description**FIELD OF THE INVENTION**

5 The present invention relates to thermosettable resin compositions and their use together with reinforcing filaments in the production of advanced composites.

BACKGROUND OF THE INVENTION

10 Thermosettable resins are well known for their use in structural adhesives, in high performance composites, and in prepregs. Composites and prepregs made from these thermosettable resins and high strength fibers such as glass, ceramics, carbon and the like provide articles having considerably less weight than the same article made from metal. The articles, however, made using these thermosettable resins have been brittle, a characteristic that necessarily seriously limits their use. Also, because the viscosity of the thermosettable resins has been either too high during
15 processing or too low during curing many of the articles are rejected because of the development of voids and imperfections in the articles.

 Efforts have been made to control the viscosity of the thermosettable resins. Flow control agents, such as fumed silica, clay, whiskers, and high molecular weight polymers, have been added to thermosettable resins. These agents increase the viscosity over all temperature ranges, often making processing difficult or impossible and frequently harm
20 the physical characteristics of the cured article.

 High performance thermosetting resins include such resins as epoxies, bismaleimides, and cyanates. These resins react with curing agents or in the presence of polymerization catalysts to yield high performance resins that have gained wide acceptance as protective coatings, electrical insulations, structural adhesives, and as a matrix resin together with reinforcing filaments in advanced composites. Where high glass transition temperatures, thermal resistance, and chem-
25 ical resistance has been attained by the cured resin, the cured resin has generally had poor physical characteristics and been brittle, had poor impact resistance and fracture properties.

 There are many references in the art teaching means for improving physical characteristics of cured thermosetting resins, primarily thermosetting epoxy resins, by use of a particular hardener and/or the addition of another polymer and/or an inorganic particulate material.

30 References among many others that teach means for improving the physical characteristics of cured thermosetting epoxy resin by the addition of a thermoplastic resin include the following:

 U. S. Patent No. 3,784,433 discloses that composites of unidirectional carbon fibers and a thermosettable resin are made by applying the resin as a continuous film to the carbon fibers, applying heat and pressure so that the resin flows about the fibers and forms a coherent structure, and then converting the resin into its solid, fusible B-stage.
35 Heating cycles can be very short as there is no solvent to evaporate, and the thin layers can be cooled quickly.

 U. S. Patent 4,524,181 discloses compositions curable to articles having reduced susceptibility to mechanical and thermal shock comprising an epoxy resin and colloidally dispersed elastomeric particles.

 U. S. Patent 4,558,078 discloses compositions useful as a prepreg comprising an epoxy prepolymer and curative and optionally a second resin that can be present homogeneously or in the form of an interpenetrating network.

40 European Patent Application 0 274 899 discloses a prepreg consisting of a fiber reinforced resin having as a separate phase fine thermoplastic or thermosetting resin particles distributed throughout the prepreg, preferably the particles are localized in the inter-layer zones of the composite material and remain as a separate phase upon curing the prepreg.

 In U.S. Patent No. 4,157,360 there is disclosed melts of dicyanates and thermoplastic polymers and in U.S. Patent
45 Nos. 4,745,215 and 4,780,507, there are disclosed blends of dicyanates and thermosetting or thermoplastic polymers. In European Patent Application 0 301 361 there are described rubber-modified cyanate ester resins and polytriazines derived therefrom and in U.S. Patent No. 4,804,740 there are described curable cyanate ester formulations containing thermoplastics. In U.S. Patent No. 4,468,497, there is disclosed bis-imides, crosslinking agents, and compatible elas-
50 tomers; the compositions of these references being useful for making prepreps.

 M. T. Blair et al. at the 33rd International SAMPE Symposium of March 7-10, 1988, presented a paper titled "The Toughening Effects of PBI in a BMI Matrix Resin" in which they disclosed the dispersion of 10% polybenzimidazole into a blend of bismaleimide and o,o'-diallylbisphenol A. Such a composition would not exhibit a "dissolution temper-
55 ature" required in the composition of the instant invention.

SUMMARY OF THE INVENTION

 Briefly, the present invention provides a thermosettable resin composition having a viscosity at temperatures used for processing and compounding similar to the viscosity of the unmodified thermosetting resin but having a significant

increase in viscosity at a higher resin curing temperatures. There is provided a thermosettable resin composition comprising:

- a) a thermosettable mixture that is liquid at a temperature in the range of 20° to 100°C comprising one or more thermosettable resins and one or more of curatives, hardeners, and catalysts for the thermosettable resins and
- b) 2 to 50 parts resin particles of one or more amorphous thermoplastic polymers per 100 parts of thermosettable mixture, said particles being dispersable in the thermosettable mixture at a temperature below the dissolution temperature of the particles, the particles having a T_g of 140°C or higher and an average diameter of at least 0.5 micrometers, a surface area of at least 1.0 m²/g, and a dissolution temperature of 50°C or higher, and less than about 25 percent of said particles being soluble in the thermosettable resin when held at temperatures up to 15°C below the dissolution temperature for at least two hours, wherein said dissolution temperature means the temperature at which the viscosity of a composition of thermosettable resin and thermoplastic particles in the absence of curatives, hardeners, or catalysts for the thermosettable resin, when raised at a rate of about 2°C per minute, reaches a minimum value and then begins to rise as the thermoplastic particles begin to dissolve;

said resin composition being free of solvent for the thermoplastic particles and having a viscosity that decreases with increasing temperature up to a dissolution temperature and that increases with increasing temperatures above the dissolution temperature, said amorphous particles being completely dissolvable in the thermosettable resin below the cure temperature of the resin, and providing a homogeneous cured resin composition.

The curative for the thermosettable resin is present in an amount sufficient for cure of the thermosettable resin, and: Preferably 2 to 30, parts per 100 parts of thermosettable mixture, of said resin particles are present. Preferably said particles have a dissolution temperature of 70° or higher. The composition may optionally contain additives for property enhancement.

The invention also provides prepreps for structural composites comprising a web of fibrous material impregnated with the thermosettable composition of the invention.

As used in this application:

"dissolution temperature" means the temperature at which the viscosity of a composition of thermosettable resin and thermoplastic particles in the absence of curatives, hardeners, or catalysts for the thermosettable resin, when raised at a rate of about 2°C per minute, reaches a minimum value and then begins to rise as the thermoplastic particles begin to dissolve.

Means disclosed in the background art for solving physical shortcomings of the cured thermosetting resin have not solved problems arising in processing of thermosetting resins into useful articles. In processing of a thermosetting resin composition into an article such as a prepreg that can be used in the manufacture of composite structures, the viscosity profile of the thermosetting resin composition is very important. It is important that the viscosity of the composition be relatively low during compounding, coating and impregnating of a fiber reinforcement but becomes relatively high during the curing process to allow the application of vacuum to remove volatiles and the application of pressure to shape the composite part without bleeding of excessive amounts of resin that would cause voids and imperfections in the cured composite part.

BRIEF DESCRIPTION OF THE DRAWING

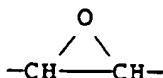
Aspects of the invention which are capable of illustration are shown in the accompanying Drawing wherein graphs show the relationship of viscosity to temperature for compositions according to the invention and for state-of-the-art compositions.

In the Drawing (details of the formulation and procedures are given in Example 1, below), curve A (comparative) represents the viscosity profile for a conventional thermosetting resin. As can be seen, the viscosity decreases with increasing temperature. Curve B (comparative) is the viscosity profile for a composition of the thermosetting resin of Curve A and 8.5% by weight of polyetherimide thermoplastic. For this trial the thermoplastic has been completely dissolved into the thermoset during mixing to form a completely homogeneous blend. This formulation exhibits a viscosity profile which is well above the unmodified thermosetting resin over all temperature ranges. The formulation of curve C (present invention) is identical to that of curve B, however, in this trial, the polyetherimide thermoplastic is in particle form and is mixed into the thermoset to form a dispersion where none of the thermoplastic is dissolved. The viscosity profile obtained is unique in that, the initial viscosity is essentially the same as that for curve A. However, after the first minimum in viscosity occurs, which is the dissolution temperature (T_d), the thermoplastic particles dissolve. This raises the viscosity of the composition up to the level obtained for the homogeneous blend of Curve B.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

Thermosetting resins that can be used as component (a) in the composition of the invention are epoxy, N,N'-bismaleimide, and polycyanate monomers and prepolymers that are liquid at a processing temperature and can be cured to a thermoset resin composition at a temperature of 100°C or higher.

Epoxy monomers and prepolymers that can be used in the compositions of the invention are well known and most are commercially available. They are compounds in which there is present at least an aromatic or cycloaliphatic ring structure and one or more epoxy groups, e.g.,



Compounds having more than one epoxy group are preferred. Aromatic polyepoxides, the most preferred epoxy compounds, are the polyglycidyl ethers of polyhydric phenols, glycidyl esters of aromatic carboxylic acid, and polyglycidyl derivatives of aromatic amines such as N-glycidylaminobenzene, and glycidylamino-glycidylbenzenes.

Examples of aromatic polyepoxides, useful in the thermosettable resin composition of the invention, include the polyglycidyl derivatives of polyhydric phenols such as 2,2-bis[4-(2,3-epoxypropoxy)phenyl]propane and those described in U.S. Patent Nos. 3,018,262 and 3,298,998, and in "Handbook of Epoxy Resins" by Lee and Neville, McGraw-Hill Book Co., New York (1967). A preferred class of poly(glycidyl ether)s of polyhydric phenols of use in the compositions of the invention are the diglycidyl ethers of bisphenols that have pendent carbocyclic groups such as those described in U.S. Patent No. 3,298,998, which is incorporated herein by reference. Examples of such diglycidyl ethers are

2,2-bis[4-(2,3-epoxypropoxy)phenyl]norcamphane,

9,9-bis[4-(2,3-epoxypropoxy)phenyl]fluorene, and

2,2-bis[4-(2,3-epoxypropoxy)phenyl]decahydro-1,4,5,8-dimethanonaphthalene. A much preferred diglycidyl ether is diglycidyl ether of bisphenol A.

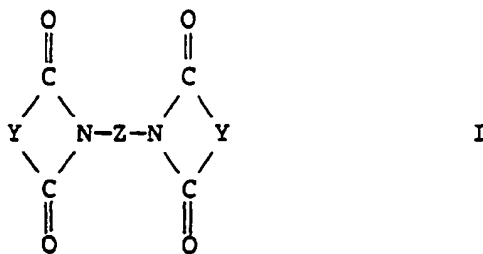
Examples of N-glycidylaminobenzenes suitable for use in the epoxy resin composition of the invention include the di and polyglycidyl derivatives of benzenamine, benzene diamines, naphthylenamine and naphthylene diamine such as N,N-diglycidylbenzenamine, N,N-diglycidyl-naphthalenamine [given the name of N-1-naphthalenyl-N-(oxiranylmethyl)oxiranemethanamine by Chemical Abstracts 9th Coll. Index, Vol. 76-85, page 2660 CS (1972-76)], 1,4-bis(N-glycidylamino)benzene, 1,3-bis(N,N-diglycidylamino)benzene, and bis[4-(diglycidylamino)phenyl]methane (MY 720™, Ciba Geigy, Inc.). The polyglycidyl derivatives of aromatic aminophenols are described in U.S. Patent No. 2,951,825. An example of these compounds is N,N-diglycidyl-4-glycidylbenzenamine (ERL 0510™, Ciba Geigy, Inc.).

When component (a) of the composition of the invention contains an epoxy monomer or prepolymer it can be cured by a variety of curing agents as are known in the art, some of which are described, together with the method for calculating the amount to be used, in the book by Lee and Neville, "Epoxy Resins," pages 36 to 140, McGraw-Hill Book Company, New York, 1957. Useful curing agents include amines such as ethylenediamine, diethylenetriamine, aminoethylethanolamine, diaminodiphenylsulfone, 9,9-bis(4-aminophenyl)fluorene, 2,7-dichloro-9,9-bis(4-aminophenyl)fluorene, an amide such as dicyandiamide, organic acids such as adipic acid, and acid anhydrides such as phthalic anhydride and chlorendic anhydride, and polyphenols such as bisphenol A.

The curing agent is chosen such that very little if any polymerization of the epoxy takes place under about 100°C but does take place with increasing rapidity as the temperature is increased above about 125°C. Generally, the epoxy composition and curing agent are used in stoichiometric amounts. However, the curing agent can be used in amounts ranging from about 0.1 to 1.5 times the stoichiometric amount of epoxy resin.

Thermally activated catalytic agents may also be used, e.g., Lewis acids and bases, tertiary amines, imidazoles, complexed Lewis acids, and organometallic compounds and salts, such as the BF₃-amine complexes, SbF₅, and benzyldimethylamine. When a thermally activated catalyst is included, about 0.01 to 5 percent by weight of catalyst, based on the amount of epoxy compound present in the thermosettable resin composition, is used.

N,N'-bismaleimide monomers and prepolymers that can be used in the composition of the invention are also well known, many of which can be purchased commercially. They are compounds in which there is present at least one, preferably two, maleimido groups and have general formula I:



where Y represents an alkylene group of at least 2 carbon atoms, preferably 2 to 6 carbon atoms, and Z is a divalent organic group containing at least 2 carbon atoms and generally no more than 20 carbon atoms. Z may be aliphatic, cycloaliphatic, aromatic or heterocyclic, these groups optionally having up to two of each of sulfur and non-peroxidic oxygen heteroatoms. Y may be derived from dicarboxylic acids or anhydrides such as maleic, citraconic and tetrahydrophthalic.

Representative N,N'-bis-imides that may be employed are the N,N'-bismaleimides of 1,2-ethanediamine, 1,6-hexanediamine, trimethyl-1,6-hexanediamine, 1,4-benzenediamine, 4,4'-methylenebisbenzenamine, 2-methyl-1,4-benzenediamine, 3,3'-methylenebisbenzenamine, 3,3'-sulfonylbisbenzenamine, 4,4'-sulfonylbisbenzenamine, 3,3'-oxybisbenzenamine, 4,4'-oxybisbenzenamine, 4,4'-methylenebiscyclohexanamine, 1,3-benzenedimethanamine, 1,4-benzenedimethanamine, and 4,4'-cyclohexanebisbenzenamine and mixtures thereof. Other N,N'-bis-maleimides and their process of preparation are disclosed in U.S. Pat. Nos. 3,562,223, 3,627,780 and 3,839,358.

The preparation of the N,N'-bismaleimides is well known and described in U.S. Patent No. 4,468,497. The N,N'-bismaleimides are polymerized by heating them together with a diamine into which they can be dissolved at temperatures of 100°C or lower and optionally a diunsaturated crosslinking agent.

Diamines that can be used in polymerizing the N,N'-bismaleimides are described in U.S. Patent No. 3,562,223. Preferred diamines which may be employed are diamines having a cycloalkyl or aryl group, and are the same as those listed above, that are of use in the preparation of the N,N'-bismaleimides.

Generally, from about 0.2 to 0.8 moles of diamine are used per mole of N,N'-bismaleimide.

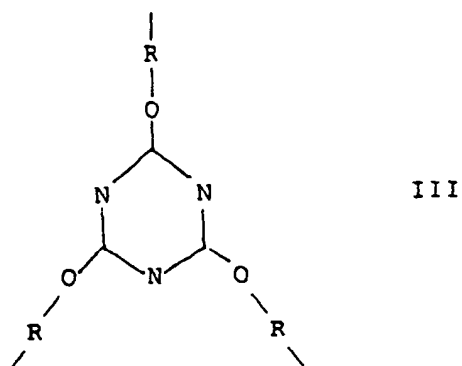
Diunsaturated cross-linking agents of use in the N,N'-bismaleimide compositions of the invention are any diunsaturated compounds having a boiling point at atmospheric pressure of about 150°C or higher and terminal ethylenic unsaturation. Preferred cross-linking agents are divinylbenzene, diallyl phthalate, and bis(4-allyloxyphenyl)ether.

Dicyanate monomers and prepolymers that can be used in the composition of the invention are also well known. References to their preparation and use in polycyclotrimerization to produce polycyanurates are described in U.S. Patent No. 4,157,360. The dicyanates are compounds having general formula II:



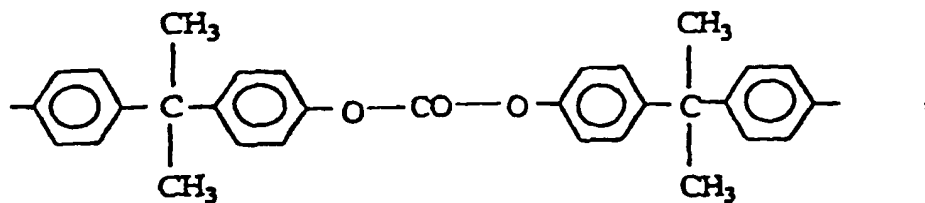
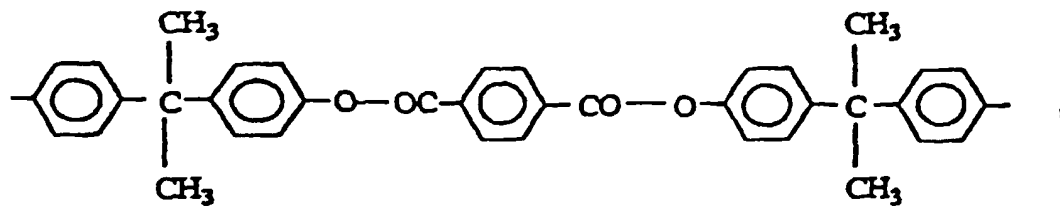
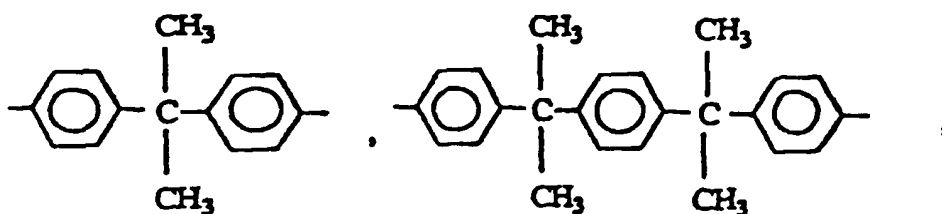
wherein R is a divalent aromatic hydrocarbon residue and comprises at least one aromatic moiety, i.e., aromatic ring including benzene, naphthalene, anthracene, phenanthrene and the like, and where R contains a total of up to 40 carbon atoms, including the aromatic moiety. For example, R can be 1,4-di(2'-phenylpropyl)benzene moiety, to which the cyanate groups are attached in the para positions of the benzene rings of the phenylpropane substituents to provide one embodiment of compounds of formula II. The aromatic rings of R may be further substituted with groups that are inert during the polymerization process, i.e., the polycyclotrimerization process, and include halogen, including fluorine, chlorine, bromine, and iodine; C₁-C₄ alkoxy, being linear or branched and including methoxy, ethoxy, isopropoxy, and t-butoxy; and C₁-C₄ alkyl carbonyloxy group, being linear or branched, including methoxycarbonyl, ethoxycarbonyl, isopropoxycarbonyl and t-butoxycarbonyl; wherein the number of substituents on the aromatic rings may be one or more with the proviso that the groups are inert during the polymerization process and do not substantially interfere with the formation of the crosslinked triazine polymer upon polycyclotrimerizing of the aromatic dicyanate moiety.

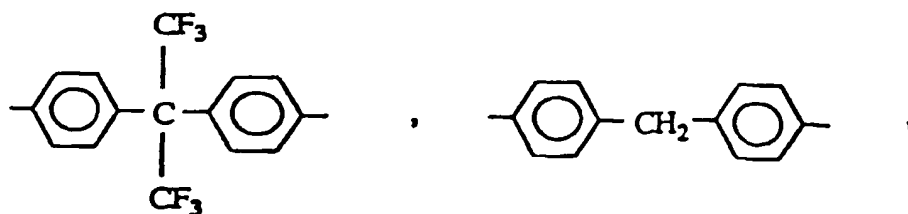
By the term "polycyclotrimerization" is meant forming a cyanurate ring system by the polymeric condensation of three aromatic cyanate groups to form a crosslinked aromatic ring system, which has as its basic repeating unit the group of formula III:



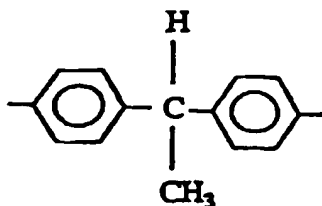
15 in which R substituents, independently as defined above, are attached to oxygen atoms. Methods for conducting the polymerization are well known, including thermal annealing above about 200°C and are described in the Korshak reference discussed in U.S. Patent No. 4,157,360, cited above.

Preferred dicyanates are those in which R in Formula III can have any of the structural formulae:





and



or combinations thereof.

When polycyanates are used in component (a) of the composition of the invention, mixtures of any proportions of polycyanates and prepolymers of the polycyanates and optionally monocyanates that are liquid at the processing temperature which preferably is in the range of 20 to 100°C can be used. Prepolymers are made by heating the blends with or without catalyst at a temperature of about 140°C to about 220°C for a time sufficient to cyclotrimerize from about 5 to about 50 percent of the cyanate functional groups.

Catalysts that can be used in cyclotrimerizing the polycyanates to form prepolymers and completely polymerized polycyanurates include zinc octoate, tin octoate, zinc stearate, tin stearate, copper acetylacetonate, phenol, catechol, triethylendiamine and chelates of iron, cobalt, zinc, copper, manganese and titanium with bidentate liquids such as catechol. Such catalysts are used in the amounts of about 0.001 to about 20 parts by weight per 100 parts of the polycyanate ester blend. Other catalysts and their use in curing polycyanates are disclosed in Great Britain Patent No. 1,305,762. It is, however, possible to conduct the formation of prepolymers and the complete polymerization without a catalyst, utilizing only heat.

Cyanate esters that can be used include RDX 80352™ a prepolymer of bisphenol A dicyanate, by Interez, Inc; XU71787™ a polycyanate of a polyphenol adduct of dicyclopentadiene by Dow Chemical Company; and BT 2160™ resin, a prepolymer of bisphenol A dicyanate containing 10% by weight of 4,4'-methylenedianiline bismaleimide, commercially available from Mitsubishi Gas Chemical Company.

Resin particles which can be used as component (b) in the thermosettable resin composition of the invention have a dissolution temperature above 50°C, preferably above 70°C, and are insoluble in the thermosettable resin at temperatures up to 15°C below the dissolution temperature but soluble at a temperature below the onset of curing which varies depending on the resin but generally is in the range of 100 to 200°C.

The resin particles are prepared from amorphous thermoplastic resins having a glass transition temperature above 140°C. Resin particles having the required solubility characteristics have a solubility in the thermosettable resin that is low enough to prevent the particles from dissolving when the particles are mixed into the thermosettable resin or during storage of the thermosettable mixture. The resin particles, however, also have a solubility sufficient to allow the particles to be completely dissolved in the thermosettable resin during the cure cycle of the composition.

Thermoplastic resins suitable for preparation of the resin particles of the invention are amorphous thermoplastics including polycarbonates, polysulfones, polyarylates, polyethersulfones, polyarylsulfones, polyesters, polyetherimides, polyamideimides, polyimides, polyamides, and polyethers. Preferred thermoplastic resins are polyetherimides such as ULTEM™ 1000, available from General Electric polyethersulfone, such as Victrex™ 4800P, available from ICI, and polyarylsulfone, such as Radel™ A-200 available from Amoco. The suitability of a particular thermoplastic resin is dependent on meeting the above solubility characteristics in the specific thermosettable resin being used in the thermosettable resin composition.

The resin particles having the desired solubility characteristics can be prepared by a variety of well know techniques, including techniques such as grinding of the solid amorphous thermoplastic resin, spray drying of solutions of the amorphous thermoplastic resin, or coagulation of emulsions of the amorphous thermoplastic resin. Suitable particles have a surface area of at least 1.0 m²/g or greater. Particle sizes generally are in the range of 0.5 to 50 micrometers, preferably 1 to 40 micrometers.

The surface area of the amorphous resin particle is important. The surface area of the particle controls the dissolution rate of the thermoplastic particle into the thermosetting resin to form a homogeneous solution. If the surface area is too low the dissolution rate is slow and can result in the thermosetting resin curing before the particle can dissolve. If the particle does not dissolve prior to curing the desirable enhanced viscosity will not be imparted.

5 Particles having high surface area can be prepared in several ways. A small particle has a high surface area. These particles can be prepared by grinding or coagulation of a polymer dispersion. Another method of obtaining a high surface area is to prepare porous particles. Porous particles can be obtained by spray drying solutions of amorphous thermoplastics, as is known in the art.

10 The solubility characteristics of a particular resin particle can be adjusted, i.e., the dissolution temperature lowered, by the incorporation of a plasticizer, i.e., from about 5 to 50 percent by weight, into the thermoplastic resin from which the resin particle is prepared. Preferably, the plasticizer has a functional group that will copolymerize with the thermosettable resin, i.e. a reactive plasticizer. As examples, an epoxy resin, for example the diglycidyl ether of bisphenol A, can be used to plasticize a particle to lower its dissolution temperature, i.e., increase its rate of dissolution into an epoxy resin or a cyanate resin composition. For example, an amine can be used to plasticize a particle to increase its

15 rate of dissolution into N,N'-bismaleimide monomers and prepolymers. By the phrase "essentially insoluble", it is meant that generally less than about 25% of the particles dissolve when the composition is held at a temperature of 15°C less than the dissolution temperature for at least two hours, such that the viscosity of a composition of the thermoplastic particles in the thermosettable resin does not change significantly, i.e., to a point making processability difficult.

20 The thermosettable compositions of the invention are suitable for use as impregnating, laminating or molding resins. They can be used as sealants, insulating materials and adhesives. They are particularly suitable for use in prepreps for the production of space age reinforced composite structures.

25 The thermosettable resin composition of the invention can be used to impregnate woven or non-woven webs, filaments, rovings or the like at a temperature below the dissolution temperature in the preparation of prepreps. Fibers that can be used in such prepreps include organic and inorganic fibers including, for example, glass fibers, carbon or graphite fibers, ceramic fibers, boron fibers, silicon carbide fibers, polyimide fibers and mixtures thereof. The thermosettable composition of the invention can also be used to coat woven and non-woven webs, films and foils of organic and inorganic materials including, for example, such organic materials as polyolefins, polyesters, polyimide, and inorganic materials such as ceramics, copper, and nickel, and gold. These materials can be useful in printed circuit technology and as structural components for machinery.

30 The composition of the invention can also contain additives to modify characteristics of the cured composition. Additives among others that can be used include: inert fillers, tougheners, whiskers, pigments, dyes and flame retardants such as, for example, chopped fibers such as ceramic fibers, glass fibers, boron fibers, carbon fibers, and their woven and nonwoven fabrics; inorganic powders such as kaolin, chalk, silica, antimony trioxide, titanium oxide, carbon; and solid microspheres of glass, ceramic, and metal.

35 The thermosettable compositions of the invention are prepared by dispersion of the thermoplastic particles, curatives, hardeners, catalysts, and modifying additives into the thermosettable resin at a temperature at which the thermosettable resin is liquid, generally at about 30 to 60°C but below the dissolution temperature of the particle in the thermosettable resin. The dispersion of the particles into the thermosettable resin is generally accomplished by conventional high shear mixing devices, such as by use of a planetary mixer, kneader, vacuum mixer, ball mill, paint mill or high speed stirrer. When the mixed composition is then maintained at a temperature of 15°C or more below the dissolution temperature, the composition is stable against gelling for two hours or longer.

40 While these thermosettable compositions of the invention are generally processed by hot melt coating techniques, organic solvents such as methyl ethyl ketone, toluene, tetrahydrofuran, ethyl acetate, ethyl alcohol, etc., can also be used to process these resin compositions. For example, solvent processing may be desirable to prepare a thin adhesive film from these thermosettable compositions. When solvents are used care must be used to select a solvent that will dissolve the liquid thermosetting resin but will not dissolve the thermoplastic particle. Suitable substrates for coating the compositions of the invention include sheets and foils of polyimide, polyester, polyolefin, metal, and the like, and fibers such as carbon, glass, aramide, ceramic, and the like.

50 Objects and advantages of this invention are further illustrated by the following examples, but the particular materials and amounts thereof recited in these examples, as well as other conditions and details, should not be construed to unduly limit this invention. In the examples all parts and percentages are by weight and temperatures are in degrees centigrade unless otherwise noted.

55 In the examples which follow, the viscosity profiles were obtained using an RDA-700™ Dynamic Mechanical Analyzer (Rheometrics, Inc.). The instrument was used in the parallel-plate mode under the following conditions: gap = 1 mm, radius = 19.02 mm, frequency = 100 rad/sec, strain = 20%, temperature ramp at 2°C/min, initial temperature = 50°C, and final temperature = 177°C.

Example 1

A thermosettable resin composition was prepared by mixing 35 parts of 9,9-bis[4-(2,3-epoxypropoxy)-phenyl]fluorene (DGF) and 65 parts of diglycidyl ether of bisphenol A (DGEBA). The resin composition was then used in three formulations: into Formulation A, no additional material was added; into Formulation C, 8.5% by weight of a particulate PEI (ULTEM resin, a polyetherimide resin available from General Electric) having a particle size of 3.2 microns and a surface area of about 5.4 m²/g was dispersed into the resin composition at 60°C using an air stirrer; Formulation B was the same as Formulation C, however the mixture was heated to 120°C and stirred to allow the thermoplastic ULTEM to completely dissolve into the resin composition. The viscosity profile of each formulation was determined using the RDA-700 Dynamic Mechanical Analyzer described above and plotted in Figure 1. Curve A, for unmodified resin composition shows a steady decrease in viscosity as the temperature of the composition is increased. Curve C, for the resin composition modified with particulate thermoplastic, shows about the same decrease in viscosity of the mixture as for the unmodified resin composition as the temperature is increased up to the dissolution temperature, T_d, where the thermoplastic begins to dissolve. At this temperature the viscosity increase, due to the dissolving thermoplastic particles, offsets the viscosity decrease of the resin composition alone and prevents further decrease in the viscosity of the mixture. Curve B, for the resin composition modified with dissolved thermoplastic shows an initial viscosity much higher than the viscosity of the composition modified with particulate thermoplastic. Formulation C thus provides the low viscosities desirable at the initial temperatures of a processing operation, e.g., prepreg fabrication, and the higher viscosities (i.e., controlled flow) that are advantageous at cure temperatures to insure void-free cured composites.

Example 2

Thermosettable resin compositions were prepared as shown in Table I.

TABLE I

Composition				
Formulation	Thermosettable Resin	% Thermoplastic particle ^d	T _d °C	Minimum Viscosity (poise)
D	(a)	None	(e)	0.36
E	(a)	8.5	115	4.78
F	(b)	None	(e)	0.15
G	(b)	8.5	119	2.55
H	(c)	None	(e)	1.20
I	(c)	8.5	115	10.60

(a) Thermosettable resin is 100 parts of 4,4'-tetraglycidyl diamine (TGDDM) and 31 parts of 4,4'-diaminodiphenylsulfone (DDS) mixed at 120°C with an air stirrer to completely dissolve the DDS.

(b) Thermosettable resin is AroCy B-30™, a dicyanate available from Hi-Tek Polymers Inc.

(c) Thermosettable resin is Compimide™, a bismaleimide resin available from Shell Chemical Co.

(d) PEI thermoplastic particle (disclosed in Example No. 1).

(e) Thermosettable resin without the thermoplastic particle does not reveal a dissolution temperature, T_d.

Viscosity profiles of each formulation was determined using the RDA-700 Dynamic Mechanical Analyzer and the dissolution temperature, T_d, and minimum viscosity of each recorded in Table I. Each of the thermosettable resins, an epoxy, a dicyanate, and a bismaleimide show minimum viscosities of 0.36, 0.15, and 1.20 poise, respectively while these thermosettable resins to which 8.5% by weight of thermoplastic particulate resin have been added show a dissolution temperature of 115°, 119°, and 115°, respectively, and a corresponding minimum viscosity of 4.78, 2.55, and 10.60 poise, respectively.

Example 3

Thermosettable compositions of a fluorene epoxy resin PR-500 (3M), with various thermoplastic resins were prepared by mixing 4.65 parts of each thermoplastic resin shown in Table II with 50 parts of PR-500 at 60°C using an air stirrer. The viscosity profile of each mixture as well as that of the composition without added particulate thermoplastic was obtained and minimum viscosity and dissolution temperature of each recorded in Table II.

TABLE II

Composition				
Formulation	Thermosettable Resin	% Thermoplastic particle (Tg) ¹	T _d °C	Minimum Viscosity (poise)
J	PR-500 ^f	None	(e)	0.30
K	PR-500 ^f	PES ^g (230)	119	1.61
L	PR-500 ^f	PC ^h (154)	74	2.34
M	PR-500 ^f	PS ⁱ (190)	86	6.50
N	PR-500 ^f	PAS ⁱ (220)	106	3.76
O	PR-500 ^f	PEI ^k (217)	106	9.30
P	PR-500 ^f	50 PAS/50PEI	106	4.15
Q	PR-500 ^f	FPE ^m (330)	105	2.80

(e) no dissolution temperature observed

(f) an aromatic epoxy resin available from 3M

(g) Victrex 4800™, a polyethersulfone available from ICI Americas, Inc.

(h) Lexan™, a polycarbonate available from General Electric Co.

(i) Udel™ P1700, a polysulfone available from Amoco Performance Products, Inc.

(j) Radel™ A-200, a polyarylsulfone available from Amoco Performance Products, Inc.

(k) Ultem™ 1000, a polyetherimide available from General Electric Company

(l) The glass transition temperature of the thermoplastic resin

(m) A polyester resin prepared from a fluorene bisphenol and isophthalic/terephthalic acid (a 50/50 mole ratio)

The data of Table II show that on heating an unmodified epoxy resin, Formula J, that the viscosity dropped to a minimum of 0.30 poise while for epoxy resin modified by a variety of thermoplastic particles that were soluble at a dissolution temperature, T_d, and essentially insoluble below this temperature, the viscosity of the composition does not drop below a much higher value depending on the particular thermoplastic.

Example 4

Portions of Formulation J and Formulation O of Example 3 were degassed and cured in molds at 177°C for four hours. Fracture toughness, K_{IC} (critical plane-strain fracture toughness in Mode I), and Tensile Modulus for each cured sample were determined following the procedures of ASTM E399-83 and ASTM D638-86, respectively. Values obtained are recorded in Table III.

TABLE III

Composition				
Formulation	Thermosettable Resin	Thermoplastic Particle	K _{IC} MPa·m ^{1/2}	Tensile Modulus GPa
J	PR-500	None	0.644	3.52
O	PR-500	8.5% PEI	0.909	3.42

As the data of Table III illustrates, the addition of thermoplastic particles, PEI, that began to dissolve at a dissolution temperature but were essentially insoluble below this temperature, provided an increase of about 44% in the fracture toughness of cured resin with essentially no loss in the tensile modulus.

Example 5

A formulation of PR-500 epoxy resin and 8.5% by weight of PEI particles was examined in an RDA-700 Dynamic Mechanical Analyzer as described above with the exception that the temperature was elevated at 2°C per minute until the temperature of the formulation reached 70° whereon the temperature was held at 70°C for a two hour dwell. The viscosity of the formulation remained unchanged during this dwell time. Upon raising the temperature, the characteristic T_d was seen and the viscosity of the formulation increased.

Example 6

Illustrating control of dissolution temperature by control of the surface area of the thermoplastic particle.

Particles of PEI were prepared to have surface areas, as shown in Table IV, of about 1.0 to 9.0 square meters per gram as determined by BET ((Brunauer, Emmett, and Teller), surface areas obtained on a Quantasorb BET™ Surface Analyzer (manufactured by Quantachrome, Co.)) surface analysis. Compositions of each were prepared by mixing 4.65 parts of the particles in 50 parts of PR-500 epoxy resin at 60°C as described in Example 3 and their viscosity profiles were determined by RDA-700. The dissolution temperature, T_d , of each composition is given in Table IV.

TABLE IV

Composition	Surface Area (m ² /g)	Dissolution Temp. (°C)
R	1.01	127
S	2.65	114
T	2.73	108
U	3.60	107
V	4.73	95
W	8.98	92

From Table IV, it is to be observed that for the thermoplastic polyetherimide, PEI, that by control of the surface area from about 1.0 to 9.0, the dissolution temperature of the composition was controlled from 127° to 92°C.

Example 7 (comparative)

The viscosity profile of a 10.0 weight % composition of the particulate thermoplastic polyimide, Durimid™ (available from Rogers Corporation) in PR-500 epoxy resin was obtained by RDA-700. No dissolution temperature was observed; the composition therefore, illustrated a thermosettable composition not included in the invention.

Example 8 (comparative)

A thermosettable composition of 50 parts of PR-500 epoxy resin and 5.56 parts of conventionally ground polyetherimide thermoplastic resin, having a surface area of 0.3 m²/g, was prepared as described above and its viscosity profile obtained. No dissolution temperature was observed, the viscosity continued to drop with increasing temperature up to onset of polymerization of the epoxy resin. Prepregs prepared of this composition possessed voids and discontinuities similar to that of epoxy resin without the modifying thermoplastic.

Example 9

Three thermosettable compositions, X, Y, and Z of PR-500 epoxy resin and polyetherimide (PEI) particles having a surface area of 4.73 m²/g were prepared by mixing the components at 60°C using an air stirrer. Compositions x, Y, and Z contained 2.63 parts (5.0%), 4.65 parts (8.5%), and 5.56 parts (10.0%) of PEI, respectively, in 50 parts of PR-500 epoxy resin. Viscosity profile of each composition was obtained and the minimum viscosity observed to be 3.5 poise, 10.35 poise, and 21.22 poise respectively. This illustrated the control of viscosity that was important during the early stages of a processing operation, e.g., prepreg fabrication, that was obtained using compositions of the invention.

Example 10

A thermosettable resin composition was prepared by mixing 91.5 parts of PR-500 epoxy resin and 8.5 parts of particulate polyetherimide having a surface area of 5.37 m²/g. The mixing was performed in a planetary mixer at 35°C under vacuum. The resin composition was further processed into a resin film approximately 66 micrometers thick. The film was laminated with continuous carbon fibers (IM7™ fibers Hercules Co.) using a conventional 30 cm wide prepregging machine (available from California Graphite Machines, Inc.). Sixteen plies of prepreg made by this process were layed-up and cured by a conventional autoclave cycle, to form a void free composite panel having a glass transition temperature of 205°C, useful as a structural component in a machine.

When the procedure of Example 10 was repeated using prepreg that had not been modified with particulate thermoplastic resin, the panel obtained had many voids due to excessive resin flow.

Example 11

Illustrating the control of the dissolution temperature by plasticizing the thermoplastic particle

Plasticized polyetherimide thermoplastic particles (PEI/DGF) were prepared by dissolving 90 parts PEI and 10 parts by weight of bis[4-(2,3-epoxypropoxy)-phenyl]fluorene in 300 parts of dichloromethane, emulsifying in water and coagulating by pouring into methanol. Particles having an average diameter of 3 micrometers and a surface area of 5.40 m²/g were obtained. Into 50 g of PR-500 epoxy resin at 60°C were dispersed 4.65g of these particles and the viscosity profile of the mixture was obtained. A dissolution temperature of 95°C as compared to 106°C for the unplasticized polyetherimide particles (Example 3) was obtained.

Example 12

Formulations AA, BB, and CC were prepared, each to contain 50 parts of epoxy resin mixture of 35% bis[4-(2,3-epoxypropoxy)phenyl]fluorene (DGF) and 65% of diglycidyl ether of bisphenol A (DGEBA) and 4.65 parts, respectively, of polysulfone (PS), PEI/DGF (the epoxy plasticized polyetherimide described in Example 11), and polyetherimide PEI (the polyetherimide as used in Example 3) by mixing at 60°C using an air stirrer. An RDA-700 viscosity profile of each was obtained, each including a dwell period at a temperature about 15°C below the dissolution temperature. Table V shows the dissolution temperature, the dwell temperature, and the viscosity at the beginning and end of the two hour dwell time.

TABLE V

Formulation	T _d (°C)	Temp. (°C) of Dwell	Viscosity (poise) Initial Final	
AA	86	70	10.8	11.0
BB	95	80	4.3	4.5
CC	106	90	2.8	2.8

The data of Table V show that for compositions of the invention of a thermosettable resin and particles of thermoplastic having a dissolution temperature of 86, 95, and 106°C, respectively, can be held at a temperature about 15°C below the dissolution temperature for at least two hours without an appreciable change in the viscosity of the composition.

Example 13 (comparative)

A thermosettable composition of PR-500, an aromatic epoxy resin available from 3M, and 8.5% by weight of polybenzimidazole (PBI) particle was prepared by mixing 4.65 parts of Ultrafine PBI (Celanese Corporation) having a surface area of 12.3 m²/g with 50 parts of PR-500 at 60°C using an air stirrer. The viscosity profile for this composition showed no evidence of dissolution of PBI. The profile is essentially the same as that obtained for an unmodified PR-500 composition.

Claims

1. A thermosettable resin composition comprising:

- a) a thermosettable mixture that is liquid at a temperature in the range of 20° to 100°C comprising one or more thermosettable resins and one or more of curatives hardeners, and catalysts, for the thermosettable resins and
- b) 2 to 50 parts resin particles of one or more amorphous thermoplastic polymers per 100 parts of thermosettable mixture, said particles being dispersable in the thermosettable mixture at a temperature below the dissolution temperature of the particles, the particles having a T_g of 140°C or higher and an average diameter of at least 0.5 micrometers, a surface area of at least 1.0 m²/g, and a dissolution temperature of 50°C or higher, and less than about 25 percent of said particles being soluble in the thermosettable resin when held at temperatures up to 15°C below the dissolution temperature for at least two hours, wherein said dissolution temperature means the temperature at which the viscosity of a composition of thermosettable resin and thermoplastic particles in the absence of curatives, hardeners, or catalysts for the thermosettable resin, when raised at a rate of about 2°C per minute, reaches a minimum value and then begins to rise as the thermoplastic particles begin to dissolve; said resin composition being free of solvent for the thermoplastic particles and

having a viscosity that decreases with increasing temperature up to a dissolution temperature and that increases with increasing temperatures above the dissolution temperature, said amorphous particles being completely dissolvable in the thermosettable resin below the cure temperature of the resin, and providing a homogeneous cured resin composition.

2. The composition according to claim 1 wherein said thermosettable resin is at least one of aromatic epoxy, cycloaliphatic epoxy, N,N'-bismaleimide, and polycyanate monomers and prepolymers.
3. The composition according to any one of claims 1 and 2 wherein said resin particles are at least one of polyesters, polyethers, polycarbonates, polyamides, polyimides, polyetherimides, and polyamideimides, polyarylates, polysulfones, polyarylsulfones, and polyethersulfones.
4. The composition according to any one of claims 1 to 3 wherein said curative is an amine, an amide, an organic acid or anhydride, or a polyphenol, and wherein said catalyst is selected from organometallic compounds or salts, Lewis acids or bases, imidazoles, tertiary amines, and complexed Lewis acids.
5. The composition according to any one of claims 1 to 4 wherein said resin particles further comprise an effective amount of a plasticizer to increase the rate of dissolution of said resin particles.
6. The composition according to any one of claims 1 to 5 further comprising an effective amount of at least one of inert fillers, tougheners, whiskers, pigments, dyes, and flame retardants.
7. A prepreg comprising reinforcing filaments and the composition according to any one of claims 1 to 6.
8. An article comprising a woven or nonwoven web, film, or foil coated with the composition according to any one of claims 1 to 7.

Patentansprüche

1. Wärmehärtbare Harzzusammensetzung, umfassend:

a) eine wärmehärtbare Mischung, die bei einer Temperatur im Bereich von 20° bis 100°C flüssig ist, umfassend ein oder mehrere wärmehärtbare Harze und ein oder mehrere von Härtmitteln, Härttern und Katalysatoren für die wärmehärtbaren Harze, und

b) 2 bis 50 Teile Harzteilechen von einem oder mehreren amorphen thermoplastischen Polymeren pro 100 Teilen der wärmehärtbaren Mischung, wobei die Teilchen in der wärmehärtbaren Mischung bei einer Temperatur unterhalb der Auflösungstemperatur der Teilchen dispergierbar sind, wobei die Teilchen einen Glasübergangspunkt Tg von 140°C oder mehr und einen durchschnittlichen Durchmesser von mindestens 0,5 µm, eine Oberfläche von mindestens 1,0 m²/g und eine Auflösungstemperatur von 50°C oder mehr besitzen, und wobei weniger als etwa 25% der Teilchen in dem wärmehärtbaren Harz löslich sind, wenn sie für mindestens zwei Stunden bei Temperaturen bis zu 15°C unter der Auflösungstemperatur gehalten werden, wobei mit Auflösungstemperatur die Temperatur gemeint ist, bei der die Viskosität einer Mischung aus wärmehärtbarem Harz und thermoplastischen Teilchen ohne Härtmittel, Härter oder Katalysatoren für das wärmehärtbare Harz, wenn die Temperatur um jeweils etwa 2°C pro Minute angehoben wird, einen Mindestwert erreicht und dann allmählich ansteigt, wenn die thermoplastischen Teilchen sich aufzulösen beginnen;

wobei die Harzzusammensetzung kein Lösungsmittel für die thermoplastischen Teilchen enthält und eine Viskosität besitzt, die mit bis zu einer Auflösungstemperatur steigender Temperatur abnimmt und mit über die Auflösungstemperatur steigenden Temperaturen zunimmt, wobei die amorphen Teilchen in dem wärmehärtbaren Harz unterhalb der Härtungstemperatur des Harzes vollständig lösbar sind und eine homogene gehärtete Harzzusammensetzung ergeben.

2. Zusammensetzung nach Anspruch 1, bei der das wärmehärtbare Harz wenigstens eines von aromatischen Epoxidharz-, cycloaliphatischen Epoxidharz-, N,N'-Bismaleimid- und Polycyanatmonomeren und -vorpolymeren ist.
3. Zusammensetzung nach einem der Ansprüche 1 und 2, bei der die Harzteilechen wenigstens eines von Polyestern, Polyethern, Polycarbonaten, Polyamiden, Polyimiden, Polyetherimiden und Polyamidimiden, Polyarylaten, Poly-

sulfonen, Polyarylsulfonen und Polyethersulfonen sind.

4. Zusammensetzung nach einem der Ansprüche 1 bis 3, bei der das Härtungsmittel ein Amin, ein Amid, eine organische Säure oder ein Anhydrid oder ein Polyphenol ist, und bei der der Katalysator ausgewählt ist aus metallorganischen Verbindungen oder Salzen, Lewis-Säuren oder -Basen, Imidazolen, tertiären Aminen und komplexen Lewis-Säuren.
5. Zusammensetzung nach einem der Ansprüche 1 bis 4, bei der die Harzteilechen des weiteren eine wirksame Menge eines Weichmachers enthalten, um die Auflösungsgeschwindigkeit der Harzteilechen zu erhöhen.
6. Zusammensetzung nach einem der Ansprüche 1 bis 5, des weiteren umfassend eine wirksame Menge von wenigstens einem von inerten Füllstoffen, Schlagfestmachern, Whiskers, Pigmenten, Farbstoffen und Flammschutzmitteln.
7. Prepreg umfassend Verstärkungsfilamente und die Zusammensetzung nach einem der Ansprüche 1 bis 6.
8. Gegenstand umfassend ein Gewebe oder Vlies, einen Film oder eine Folie, die mit der Zusammensetzung nach einem der Ansprüche 1 bis 7 beschichtet sind.

Revendications

1. Composition de résine thermodurcissable comprenant :

a) un mélange thermodurcissable qui est liquide à une température allant de 20 à 100°C, comprenant une ou plusieurs résines thermodurcissables et un ou plusieurs composés parmi les durcisseurs à chaud, les durcisseurs et les catalyseurs pour les résines thermodurcissables, et
 b) 2 à 50 parties de particules de résine d'un ou plusieurs polymères thermoplastiques amorphes, pour 100 parties de mélange thermodurcissable, lesdites particules étant dispersibles dans le mélange thermodurcissable à une température inférieure à la température de dissolution des particules, les particules ayant une Tg de 140°C ou davantage et un diamètre moyen d'au moins 0,5 µm, une aire spécifique d'au moins 1,0 m²/g et une température de dissolution de 50°C ou davantage, et moins d'environ 25 % desdites particules étant solubles dans la résine thermodurcissable quand on la maintient à une température allant jusqu'à 15°C en dessous de la température de dissolution et pendant au moins deux heures, ladite température de dissolution étant la température à laquelle la viscosité d'une composition de résine thermodurcissable et de particules thermoplastiques, en l'absence de durcisseurs à chaud, de durcisseurs ou de catalyseurs pour la résine thermodurcissable, quand on l'élève à une vitesse d'environ 2°C par minute, atteint une valeur minimale et ensuite commence à augmenter quand les particules thermoplastiques commencent à se dissoudre ; ladite composition de résine étant exempte de solvant pour les particules thermoplastiques et ayant une viscosité qui diminue quand la température augmente jusqu'à la température de dissolution, et qui augmente quand la température augmente au-delà de la température de dissolution, lesdites particules amorphes pouvant être complètement dissoutes dans la résine thermodurcissable à une température inférieure à la température de durcissement de la résine, et donnant une composition de résine durcie homogène.

2. Composition selon la revendication 1, dans laquelle ladite résine thermodurcissable est au moins l'un des composés choisis parmi les composés époxy aromatiques, les composés époxy cycloaliphatiques, le N,N'-bismaléimide, et les monomères et prépolymères de polycyanate.
3. Composition selon l'une quelconque des revendications 1 et 2, dans laquelle lesdites particules de résine sont en au moins l'un des composés choisis parmi les polyesters, les polyéthers, les polycarbonates, les polyamides, les polyimides, les polyétherimides, les polyamide-imides, les polyarylates, les polysulfones, les polyarylsulfones et les polyéthersulfones.
4. Composition selon l'une quelconque des revendications 1 à 3, dans laquelle ledit durcisseur thermique est une amine, un amide, un acide ou un anhydride organique, ou encore un polyphénol, et dans laquelle ledit catalyseur est choisi parmi les sels ou les composés organométalliques, les bases ou les acides de Lewis, les imidazoles, les amines tertiaires et les acides de Lewis complexés.

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5. Composition selon l'une quelconque des revendications 1 à 4, dans laquelle lesdites particules de résine comprennent en outre une quantité d'un plastifiant efficace pour augmenter la vitesse de dissolution desdites particules de résine.

5 6. Composition selon l'une quelconque des revendications 1 à 5, comprenant en outre une quantité efficace d'au moins un composé choisi parmi les charges inertes, les agents de durcissement, les fibres en barbes, les pigments, les colorants et les retardateurs de flamme.

10 7. Préimprégné comprenant des filaments de renforcement et la composition selon l'une quelconque des revendications 1 à 6.

8. Article comprenant un feuil, un film ou un mat tissé ou non-tissé, revêtu de la composition selon l'une quelconque des revendications 1 à 7.

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